BLM Technical Note 374

PEAK/RISK/CULVERT

A Program to Compute Peak Flows, Hydrologic Risk, and Circular Culvert Sizes at Forest Road Crossings

by

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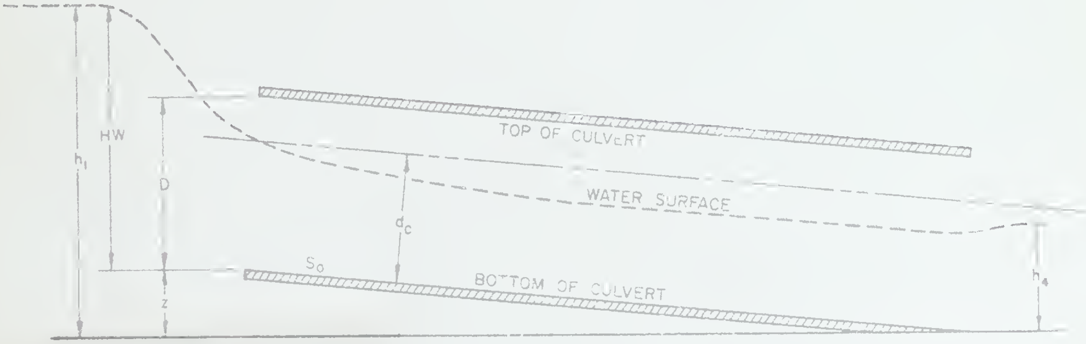

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Preface

This Technical Note describes the use of a BASIC computer program to aid the hydrologist (and other specialists involved in water projects) in the calculation of design peak flows, evaluation of hydrologic risk, and selection of circular culverts. The program is written for the sizing of circular culverts at forest road crossings, but may be extended to other applications such as bridges, watershed management projects, and other uses where the calculation of design events and hydrologic risk is needed. A discussion of each subject is included in the text, with instructions on how to use the program. Example problems are used to illustrate the program.

The peak flow portion may be adapted to other locations where regional flood frequency equations have been developed. The computational methods are described briefly. For a more detailed discussion, consult the references cited.

Introduction

Forest engineers and hydrologists frequently need to determine design peak flows and culvert sizes in the design of forest road crossings. In addition to selecting a culvert size, an assessment of the hydrologic risk should be an integral part of the final design. Often a culvert size is selected to pass a certain peak flow without considering how the culvert will perform at other discharges. A standard return period may have been selected, without considering the hydrologic risk over the anticipated life of the structure.

The BASIC program described in this Technical Note allows the user to quickly estimate peak flows for various return periods in western Oregon, using the regional flood frequency equations developed by the U.S. Geological Survey. Peak flows may also be estimated using regression equations developed by the Water Resources Research Institute, Oregon State University. The review of the two methods is brief; no attempt is made to cover all aspects of estimating peak flows using the equations. Another portion of the program answers four commonly asked questions associated with hydrologic risk. The third option concerns the sizing and performance of circular culverts. Once the user has chosen the design discharge and entrance conditions, the program selects a circular culvert size required to pass the design discharge, and then shows how that culvert performs over a wide range of headwater conditions. In the fourth option, a culvert size may be chosen beforehand along with the entrance conditions and the performance of that culvert observed. Results obtained during a typical session may be printed out for documentation.

The purpose of this Technical Note is to assist hydrologists and engineers in using the program to quickly calculate peak flows, hydrologic risk, circular culvert size and performance. It is intended to supplement and not replace engineering judgment and is only applicable for specific conditions of peak flow usually associated with circular culverts at road crossings. These conditions are noted in the text of the appropriate section of the Technical Note.

SYMBOLS AND UNITS

d	- Depth of flow in culvert	ft
d_c	- Maximum depth in critical flow section	ft
D	- Diameter of culvert	ft
E.G.L.	- Energy Grade Line	--
g	- Acceleration of gravity	ft/s^2
h	- Depth in stream channel	ft
H_o	- Specific energy	ft-lb/lb
HW	- Headwater depth	ft
S_o	- Slope of culvert	ft/ft
V	- Velocity	ft/s
$\frac{V^2}{2g}$	- Velocity head	ft
Z	- Elevation of culvert invert above datum	ft

(subscripts refer to location of cross section)

Hydrologic Risk

In water-related projects, risk is equivalent to the probability of failure of the structure. The total risk of failure is made up of both hydrologic risk and structural risk. Structural risk refers to the probability that a structure will fail during an event of lower magnitude than the design event. Hydrologic risk is composed of the true or basic risk, which is due to the vagaries of nature, and uncertainty, which is a function of measurement inconsistencies, loss of information during analysis, or non-homogeneity of the data in time. If we assume that structural risk is zero or near zero for hydrologic events not exceeding the design event, and that hydrologic uncertainty can be handled with confidence limits in the frequency analysis, then the remaining unknown variable is basic hydrologic risk (Van Haveren 1979).

Hydrologic risk may be defined as the probability that one or more events will exceed a given flood magnitude within a specified period of years. Acceptance of a given hydrologic risk, say 20 percent, means the designer is 80 percent confident that the associated hydrologic event will not be equaled or exceeded during the stated time period, and that the structure will not fail for hydrologic reasons. An excellent summary of hydrologic risk may be found in BLM Technical Note 337, "Hydrologic Risk and Return Period Selection for Water Related Projects" (Van Haveren 1979).

The term return period or recurrence interval (T), is defined as the average time interval in years between occurrences of a hydrologic event of a given or greater magnitude. The reciprocal of the return period is known as the annual exceedence probability (p), and tells the percent chance of a certain flood being equaled or exceeded in any given year.

$$p = \frac{1}{T} \qquad (1)$$

If the exceedence probability is known, then by subtraction, the probability of non-exceedence (q), may be found.

$$q = 1 - p \qquad (2)$$

The binomial distribution can be used to calculate the probability of an event occurring a certain number of times. An event is defined as a flood that either equals or exceeds a selected flood magnitude. The distribution as applied in hydrology takes the following form:

$$R_i = p^i(1-p)^{(N-i)} \quad \frac{N!}{i!(N-i)!} \qquad (3)$$

where R_i is the estimated risk of obtaining in N years exactly i number of flood events exceeding a flood magnitude with annual exceedence probability p.

When i is equal to zero (no events), then the equation reduces to:

$$R_0=(1-p)^N \quad \text{or } q^N \tag{4}$$

in which R_0 is the probability of non-exceedence of the selected flood magnitude in N years.

The complement of Equation 4 is used to find the risk of experiencing one or more events equal to or greater than the design event:

$$R = 1 - q^N \text{ or } 1-(1-p)^N \tag{5}$$

Oregon Forest Practice Rules require stream crossing structures to be designed to pass the 25-year flood. Hydrologic risk increases in accordance with Equation 5 with the length of time the structure is in place. The risk of a 25-year flood occurring in any given year is 4 percent (1/25). Over a 10-year period, the risk of one or more 25-year floods occurring is 34 percent. The risk increases to 64 percent for a 25-year period. Thus, hydrologic risk should be an integral part in the design of a stream crossing structure.

Peak Flow Estimation

Many methods for estimating peak flow at ungaged watersheds are available. Two methods commonly used in Western Oregon have been developed by the U.S. Geological Survey and the Water Resources Research Institute. No attempt is made to cover all aspects of flow estimation. Users of the Peak/Risk/Culvert program are urged to consult the original publications to become familiar with the development, use and limitations of each method.

USGS Method

The U.S. Geological Survey (USGS) has developed regional flood frequency equations for ungaged watersheds to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year floods (Harris et al. 1979). The regression equations (see Table 1) developed from gaging station records relate flood magnitude to basin characteristics in four regions of western Oregon. Figure 1 shows the boundaries of the flood frequency regions. Variables used include drainage area, area of lakes and ponds, percent forest cover, and precipitation intensity. Each basin characteristic is determined as follows:

Drainage Area (A) in square miles should be determined from the best available topographic map using a planimeter or dot grid.

Area of Lakes and Ponds (ST) is the percentage of the total drainage area occupied by lakes and ponds.

Precipitation Intensity (I) is determined from Figure 2 (fold-out in back pocket) and is the maximum 2-year, 24-hour precipitation in inches. Note that the isopluvial lines are in tenths of an inch.

Forest Cover (F) is the percentage of the drainage area covered by brush or trees. It is determined by the extent of green overprint (vegetation) shown on U.S. Geological Survey topographic maps.

Table 2 contains the range of each variable used in the regression equations. Using data outside of the applicable range is not advisable and could produce erroneous values. However, extrapolations may be done if used carefully and if qualified accordingly (Harris et al. 1979).

WRRI Method

Another method of peak flow estimation has been developed in a similar manner by the Water Resources Research Institute (WRRI) located in Corvallis, Oregon (Campbell et al. 1982). Regional regression equations of the WRRI method use the same geographic regions as in the USGS method. The equations were derived using the gaging station records of smaller watersheds, generally less than 8 square miles in area. As in the USGS method, the use of data outside of the range used in developing the equations should be done cautiously. Table 2 also contains the range of variables for the WRRI method. The equations are shown in Table 3 and may be used to estimate the 10-, 25-, 50-, and 100-year floods for an ungaged watershed. Variables used by this method include drainage area, mean basin elevation and mean annual precipitation.

Table 1. USGS regional regression equations.

Recurrence Interval in Years		Equation	Percent Standard Error
		COAST REGION	
Q(2)	=	$4.59A^{0.96}(ST+1)^{-0.45}I^{1.91}$	33
Q(5)	=	$6.27A^{0.95}(ST+1)^{-0.45}I^{1.95}$	32
Q(10)	=	$7.32A^{0.94}(ST+1)^{-0.45}I^{1.97}$	33
Q(25)	=	$8.71A^{0.93}(ST+1)^{-0.45}I^{1.99}$	34
Q(50)	=	$9.73A^{0.93}(ST+1)^{-0.44}I^{2.01}$	35
Q(100)	=	$10.7A^{0.92}(ST+1)^{-0.44}I^{2.02}$	37
		WILLAMETTE REGION	
Q(2)	=	$8.7A^{0.87}I^{1.71}$	33
Q(5)	=	$15.6A^{0.88}I^{1.55}$	33
Q(10)	=	$21.5A^{0.88}I^{1.46}$	33
Q(25)	=	$30.3A^{0.88}I^{1.37}$	34
Q(50)	=	$38.0A^{0.88}I^{1.31}$	36
Q(100)	=	$46.9A^{0.88}I^{1.25}$	37
		ROGUE-UMPQUA REGION	
Q(2)	=	$24.2A^{0.86}(ST+1)^{-1.16}I^{1.15}$	44
Q(5)	=	$36.0A^{0.88}(ST+1)^{-1.25}I^{1.15}$	43
Q(10)	=	$44.8A^{0.88}(ST+1)^{-1.28}I^{1.14}$	44
Q(25)	=	$56.9A^{0.89}(ST+1)^{-1.31}I^{1.12}$	46
Q(50)	=	$66.7A^{0.90}(ST+1)^{-1.33}I^{1.10}$	49
Q(100)	=	$77.3A^{0.90}(ST+1)^{-1.34}I^{1.08}$	51
		HIGH CASCADES REGION	
Q(2)	=	$4.75A^{0.90}(ST+1)^{-0.62}(101-F)^{0.11}I^{1.17}$	55
Q(5)	=	$8.36A^{0.86}(ST+1)^{-0.81}(101-F)^{0.08}I^{1.30}$	50
Q(10)	=	$11.3A^{0.85}(ST+1)^{-0.92}(101-F)^{0.07}I^{1.37}$	53
Q(25)	=	$15.4A^{0.83}(ST+1)^{-1.03}(101-F)^{0.05}I^{1.46}$	59
Q(50)	=	$18.8A^{0.82}(ST+1)^{-1.10}(101-F)^{0.04}I^{1.52}$	66
Q(100)	=	$22.6A^{0.81}(ST+1)^{-1.17}(101-F)^{0.03}I^{1.57}$	72

Where:

Q(n) = Peak flow in cfs; n indicates recurrence interval in years
A = Drainage area in square miles
ST = Area of lakes and ponds, in percent
F = Forest cover, in percent
I = 2-year 24-hour precipitation in inches

From Harris et al. 1979.

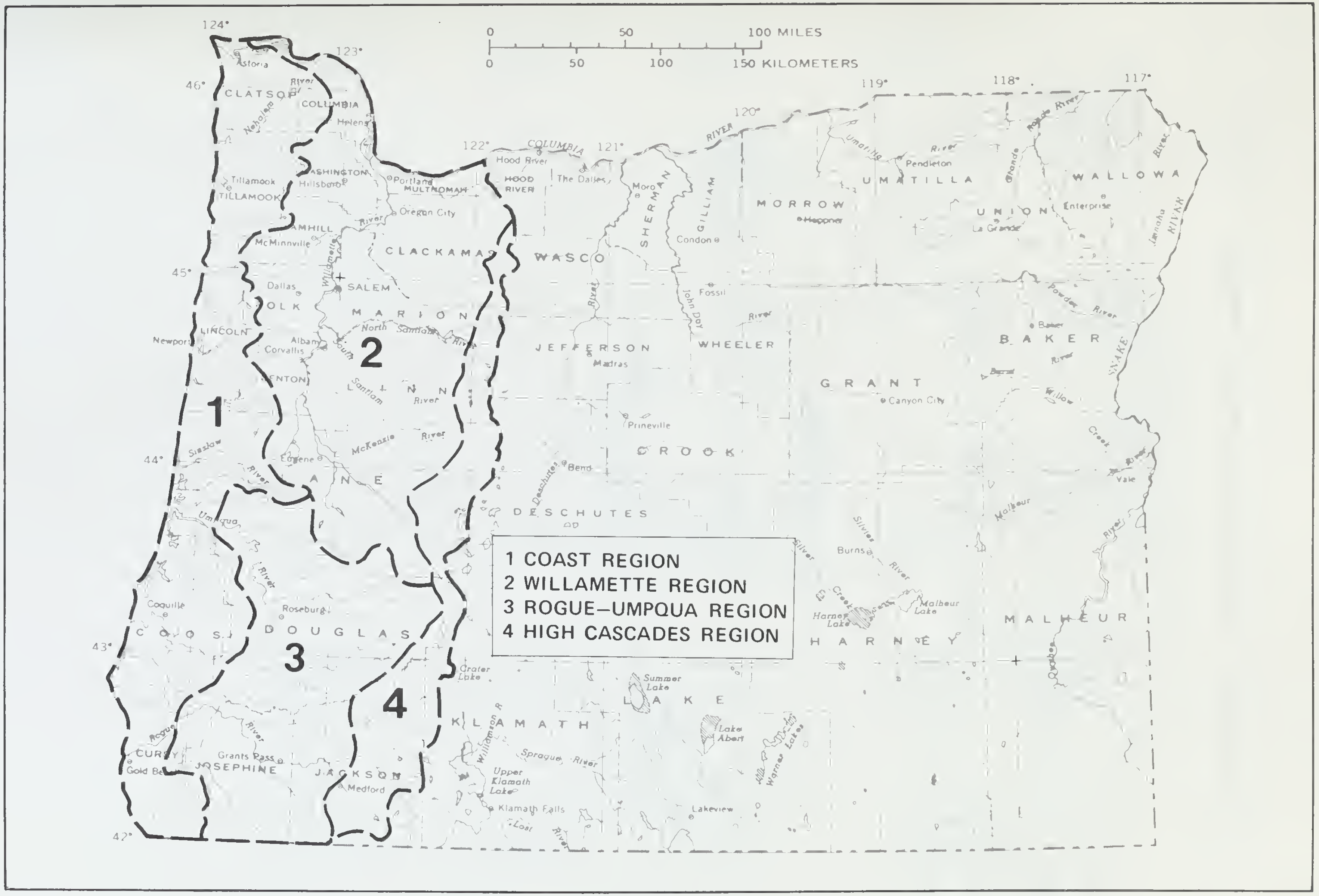

Figure 1. Flood-frequency regions of western Oregon (from Harris et al. 1979).

Table 2. Range of characteristics used in regression equations.

USGS METHOD

Region	Drainage Area in Mi^2	Percent Area in Lakes and Ponds	Percent Forest Cover	Precipitation Intensity in Inches
Coast	.27- 667	0-18.81	---	3.0-6.2
Willamette	.37-7280	----	---	2.3-5.0
Rogue-Umpqua	.75-3939	0- 4.40	---	2.5-6.2
High Cascades	.21- 650	0- 3.65	48-100	1.4-4.3

From Harris et al. 1979.

WRRI METHOD

Region	Drainage Area in Mi^2	Annual Precipitation in Inches	Mean Elevation in Feet
Coast	0.29-2.58	---	260-2820
Willamette	0.37-5.19	---	----
Rogue-Umpqua	0.75-6.42	---	----
High Cascades	0.21-8.00	50-88	----

From Campbell et al. 1982

Table 3. Regional flood-frequency equations, WRRI method.

A = Drainage basin area in square miles
E = Mean basin elevation in feet
P = Mean annual precipitation in inches

Equation	R^2	Average error (percent)	Standard error (log_{10} units)
	COAST REGION		
$Q(10) = 5.87\ A^{1.04}\ E^{.49}$	.83	25.7	.140
$Q(25) = 6.31\ A^{1.01}\ E^{.51}$	.79	27.3	.155
$Q(50) = 7.77\ A^{1.01}\ E^{.50}$	.79	26.1	.155
$Q(100) = 8.40\ A^{1.00}\ E^{.50}$	.78	26.0	.161
	WILLAMETTE REGION		
$Q(10) = 124\ A^{.79}$	.86	23.3	.129
$Q(25) = 156\ A^{.80}$	.87	23.9	.127
$Q(50) = 183\ A^{.80}$	.87	23.9	.127
$Q(100) = 212\ A^{.80}$	.86	24.1	.129
	ROGUE-UMPQUA		
$Q(10) = 125\ A^{.75}$	.39	62.7	.265
$Q(25) = 163\ A^{.77}$	.46	52.8	.240
$Q(50) = 191\ A^{.80}$	.50	48.6	.228
$Q(100) = 221\ A^{.82}$	.53	46.9	.224
	CASCADE REGION		
$Q(10) = .010\ A^{.44}\ P^{2.15}$	.80	20.4	.143
$Q(25) = .032\ A^{.44}\ P^{1.97}$	.86	16.1	.113
$Q(50) = .063\ A^{.45}\ P^{1.87}$	.81	22.0	.132
$Q(100) = .111\ A^{.46}\ P^{1.78}$	.71	26.9	.178

From Campbell et al. 1982.

Drainage Area (A) is determined from topographic maps, as in the USGS method.

Mean Basin Elevation (E) is determined by laying a grid over the drainage area and averaging the elevations of at least 25 grid intersections.

Mean Annual Precipitation (P) should be determined using a grid method as in Mean Basin Elevation.

A benefit of the WRRI method is that confidence intervals may be calculated for an individual peak flow estimate. This is useful information in increasing or decreasing peak flow estimates due to watershed condition, such as compacted soils or swampy areas. For additional information on the confidence intervals, readers should consult Campbell.

Circular Culverts and Type 1 Flow

Laboratory tests and field observations have identified two major types of culvert flow: inlet control and outlet control. For each type of control, different factors determine the hydraulic capacity of a circular culvert. The cross-sectional area of the culvert barrel (diameter), the entrance geometry and the depth of headwater primarily affect the capacity for inlet control. Outlet control involves the additional factors of culvert slope, length, roughness, and tailwater elevation.

Culvert flow has been classified by the U.S. Geological Survey into six types on the basis of the location of the control section (inlet or outlet) and the relative heights of the headwater and tailwater elevations (Bodhaine 1968). Headwater is defined as the vertical distance from the culvert invert at the entrance to the energy grade line of the entrance pool. The invert is the low point in the culvert opening at the beginning of the full cross-section of the culvert barrel. The energy grade line is a graphical representation of the energy per unit weight of water, or specific energy, relative to the bottom of the stream channel (see Figure 3). At a particular point, specific energy is the sum of the depth and the velocity head:

$$H_0 = d + \frac{V^2}{2g}$$

where: H_0 = Specific energy (ft lb/lb)
d = Depth (ft)
V = Velocity (ft/s)
g = Acceleration of gravity (ft/s^2)

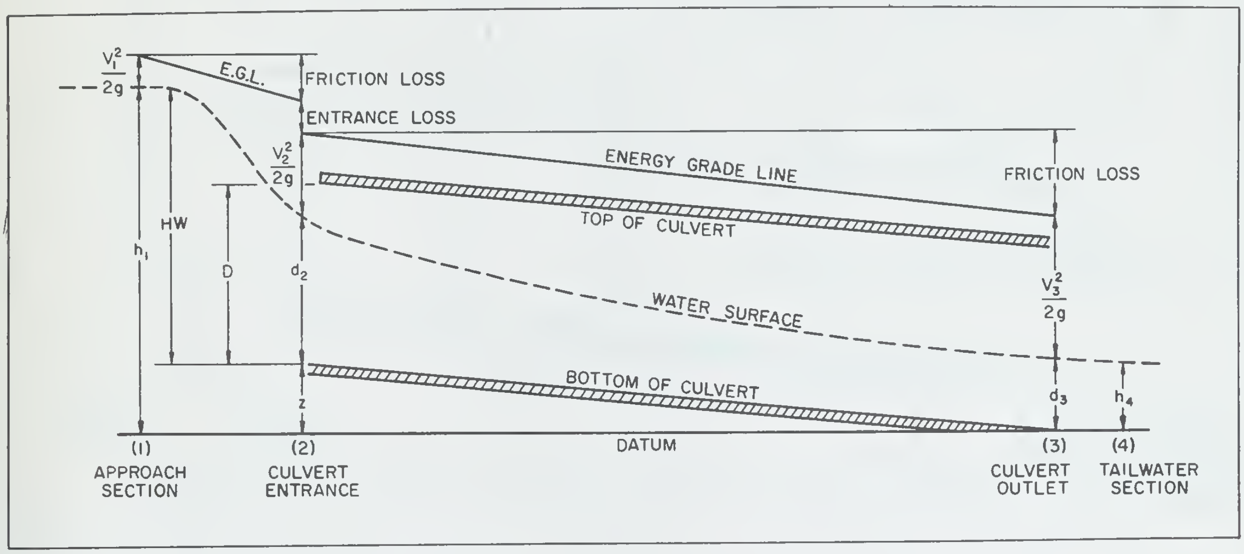

Figure 3. Definition sketch of culvert flow (from Bodhaine et al. 1968).

Because of the low velocities in most entrance pools and the difficulty in determining the velocity head for all flows, the water surface and the energy grade line at the entrance are assumed to be equal for inlet control (Herr et al. 1965). Thus, headwater is the distance from the culvert invert to the water surface at the entrance pool. A useful ratio in culvert design is the headwater divided by the culvert diameter (HW/D).

For a given discharge and channel shape, critical depth (d_c) is the depth at which specific energy is a minimum. The relationship between specific energy and depth for a constant discharge is shown in Figure 4. The slope which will sustain flow at critical depth is termed the critical slope (S_c). Milder slopes produce flow at greater depths than the critical depth, while steeper slopes produce flow at depths less than the critical depth.

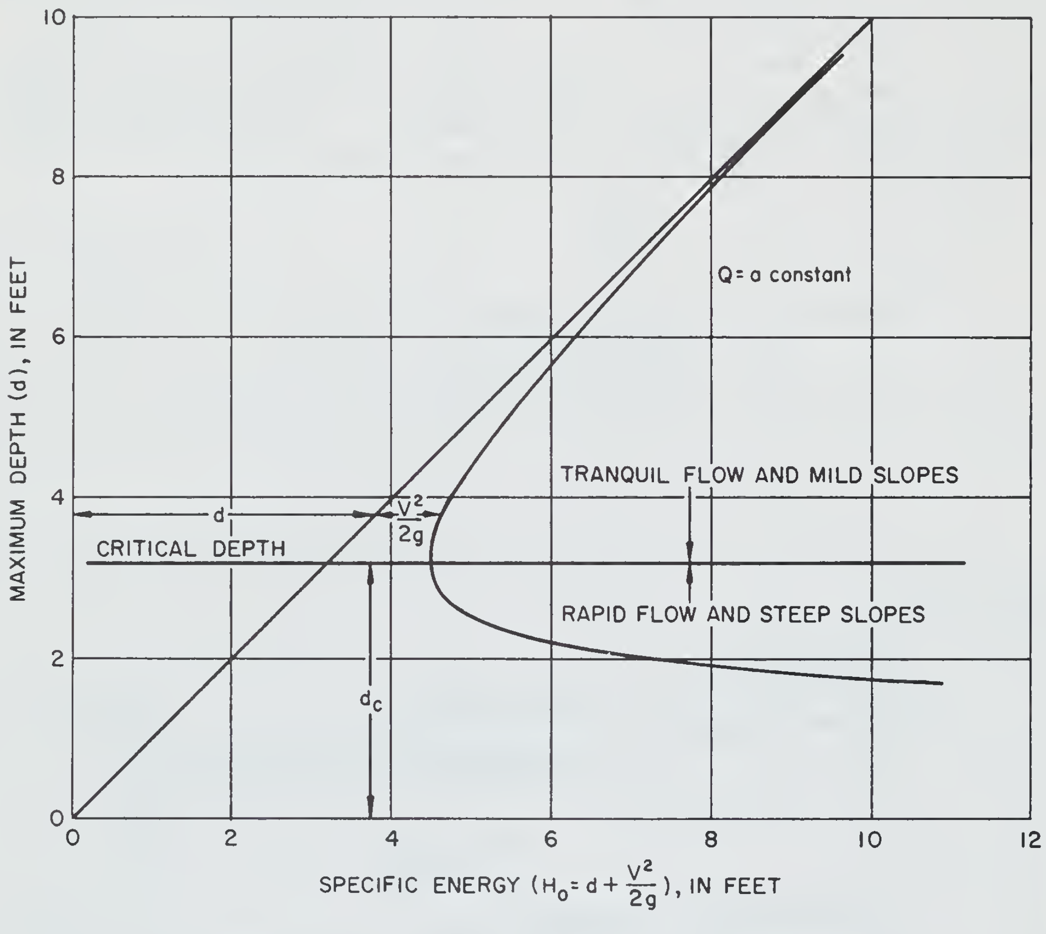

Figure 4. Relationship between specific energy and depth (from Bodhaine et al. 1968).

Figure 5 shows a type of inlet control known as Type 1 Flow. This type of flow is common at forest road crossings, where the slope of the culvert is generally greater than 1.5 percent. In Type 1 flow, the water passes through critical depth near the culvert entrance (Bodhaine 1968). For the condition of minimum specific energy and critical depth, the discharge equation for a circular culvert is:

$$Q = C_q(D)^{5/2}$$

where: Q = Discharge in cfs
C_q = Discharge coefficient, a function of d_c/D
D = Diameter in feet

The three conditions for Type 1 flow are:

1) The headwater/diameter ratio (HW/D) is less than 1.5.
2) The elevation of the tailwater is less than the water surface elevation at the control section.
3) The slope of the culvert is greater than the critical slope.

If these conditions are not met, then the culvert will not exhibit Type 1 flow. Critical slope may be calculated for a given discharge and culvert size by solving the appropriate hydraulic equation using a trial and error method. However, it is generally not necessary to do so if the culvert slope exceeds 1.5 percent. Since most culverts at forest road crossings are laid on slopes greater than 1.5 percent, inlet control or Type 1 flow will be observed. Culverts on larger streams where fish passage is a concern are designed for flow conditions other than Type 1 flow.

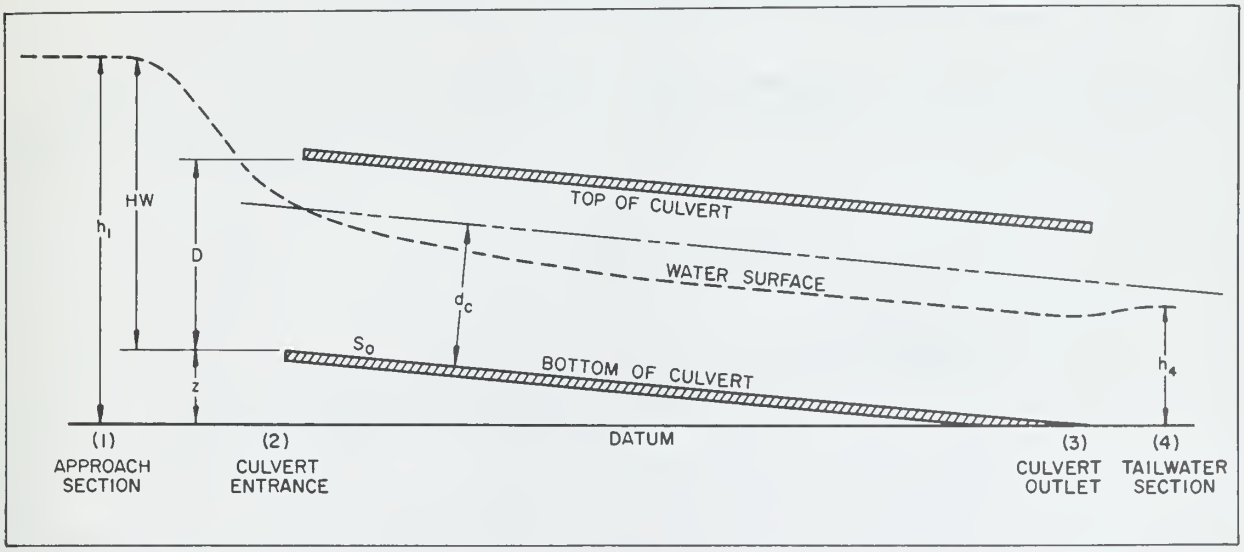

Figure 5. Sketch of Type 1 flow.

Discharge coefficients (C_q), and thus headwater for a given discharge, vary with the entrance geometry of a culvert (see Figure 6). Entrance types in increasing order of efficiency are the projecting, mitered to embankment slope, and vertical headwall. Discharge coefficients also vary with the degree of entrance beveling, entrance rounding, and length of culvert projection. However, for the purposes of evaluating culvert sizes at forest road crossings, the entrance type, culvert diameter and headwater/diameter ratio have the greatest bearing on hydraulic capacity. Other factors such as debris, sediment, and erosion may need to be considered in designing.

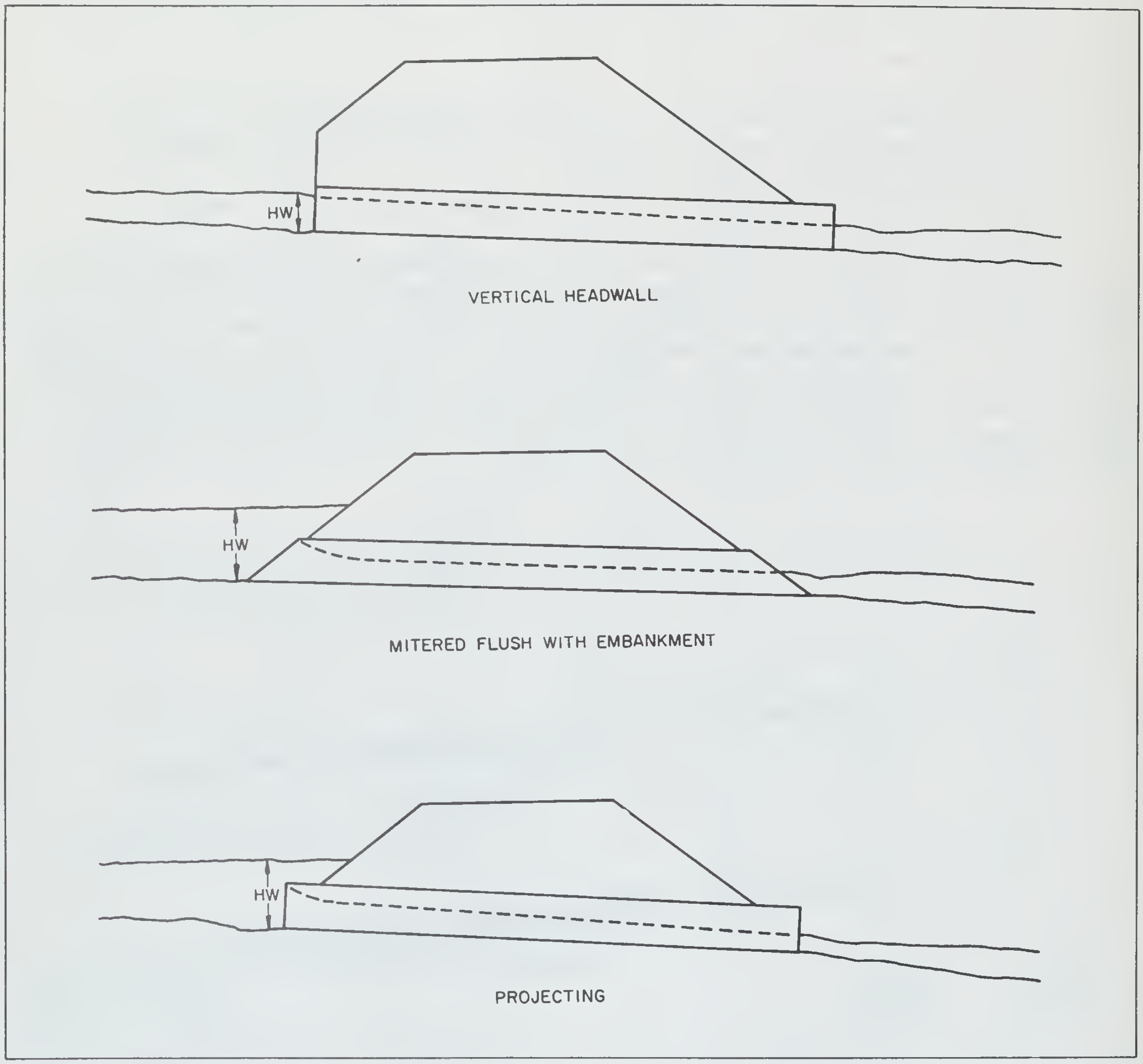

Figure 6. Culvert entrance types (from Herr et al. 1965).

Calculation of Discharge Coefficients and Culvert Diameter

The BASIC program Peak/Risk/Culvert calculates the culvert diameter for a given discharge and headwater/diameter ratio by using Equation 6 solved for the diameter:

$$D = (Q/C_q)^{2/5} \qquad (7)$$

The C_q coefficients contained in the program have been calculated from the figures and tables in "Measurement of Peak Discharge at Culverts by Indirect Methods," (Bodhaine 1968). The coefficients were calculated as follows:

1) For a pipe culvert with a square entrance, obtain the discharge coefficient C from Figure 20 or Figure 25. These are for a flush vertical headwall and mitered pipe set flush with embankment slope, respectively.

2) For a projecting pipe, adjust C by K_1 from the table on page 42. The program assumes a value of K_1 = .905 for a projecting pipe with the invert set at the toe of the embankment, and embankment slope of 1.5:1.

3) For a given headwater/diameter ratio and discharge coefficient C, find d_c/D from Figure 10.

4) Find the appropriate C_q coefficient for the above d_c/D ratio from Table 3.

Values obtained during Steps 1, 3, and 4 are shown in Table 4. Pipe sizes estimated by using the Bureau of Public Roads nomographs agree closely with those calculated by the program.

Table 4. Intermediate values in calculating C_q coefficients.

Discharge Coefficients (C)

	Headwater/Diameter Ratio										
Entrance Type	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4
Flush	.930	.929	.927	.922	.910	.895	.884	.870	.855	.841	.826
Mitered	.880	.895	.900	.902	.897	.885	.870	.845	.820	.795	.762
Projecting	.842	.841	.839	.834	.824	.810	.800	.787	.774	.761	.748

Critical Depth/Diameter Ratios (d_c/D)

	Headwater/Diameter Ratio										
Entrance Type	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4
Flush	.29	.36	.42	.48	.54	.59	.64	.68	.74	.77	.79
Mitered	.28	.35	.41	.47	.53	.58	.63	.67	.72	.75	.77
Projecting	.27	.33	.39	.45	.51	.56	.60	.64	.68	.72	.75

C_q Coefficients

	Headwater/Diameter Ratio										
Entrance Type	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2	1.3	1.4
Flush	.4893	.743	1.000	1.291	1.616	1.915	2.239	2.518	2.978	3.231	3.411
Mitered	.4571	.704	.955	1.240	1.560	1.853	2.172	2.446	2.819	3.061	3.231
Projecting	.4259	.628	.867	1.141	1.449	1.733	1.977	2.239	2.518	2.891	3.061

System Requirements to Use Peak/Risk/Culvert

The BASIC program called Peak/Risk/Culvert is intended to be used with the following microcomputer equipment:

Wang Professional Computer with BASIC language and a graphics board
Wang medium-resolution (monochrome) monitor
Wang PC-PM016 Dot Matrix Printer (Epson Dot Matrix Printer)

This is the standard microcomputer equipment for the five western Oregon BLM Districts. The program may or may not function properly with other combinations of monitors, printers, etc. For example, portions of the graphics will not be properly displayed or printed out if a color monitor is used. Additional information about program requirements and installing the program as a menu choice on the Wang is contained in Appendix 1.

How to Run the Program

The program runs initially from within the DOS Command Processor. This method was selected so that differences in each District's system configuration could be bypassed. If you need help in getting into the DOS Command Processor, ask your ADP Coordinator for help. Once you are within the DOS Command Processor, place the program diskette in disk drive A of the Wang microcomputer and close the disk drive door. Leave the diskette in the drive for the duration of the session. If you will be using the printer to print out your results, then make sure the paper is loaded and the printer is turned on and ready to use. You should see a prompt from the computer that looks like this:

C:

Type the following command immediately after the C: prompt, and push the return key to begin running the program:

A:PEAK

Relax! From this point on, the program is straightforward and easy to use. After entering the current date, you will be presented with the "main menu" of choices (see Figure 7). Simply enter your choice and follow along. To exit the program, choose that option from the main menu. You will be returned to the DOS Command Processor and then exited from there automatically. The diskette may then be removed from the disk drive.

```
        PEAK FLOW, RISK AND CULVERT SELECTION

                  SELECT OPTION

 1 )  HYDROLOGIC RISK ANALYSIS
 2 )  PEAK FLOW ESTIMATION
 3 )  SELECT CIRCULAR CULVERT USING INLET CONTROL
 4 )  VIEW PERFORMANCE OF A SPECIFIC CULVERT
 5 )  QUIT


               PLEASE CHOOSE (1-5)  ?
```

Figure 7. Main program menu.

Peak/Risk/Culvert is divided into four basic sections; it is not necessary to use all four portions during a session. The user will be prompted for any information needed by the program. If the program stops running for any reason, simply type the word RUN and push the return key to begin again.

Example Problems

Hydrologic Risk Analysis

Selecting the first option from the main menu will produce a second menu with four choices (Figure 8). Each choice shows what information will be found, given the information listed on the right side of the menu. To find the probability of one or more events occurring over a certain project life, (Question 1), the return period and project life must be specified. Given the required information, the program will then display the answer in sentence form.

```
                        HYDROLOGIC RISK ANALYSIS

          FIND:                                    GIVEN:

1 )  RISK OF ONE OR MORE                   RETURN PERIOD, PROJECT LIFE
     EVENTS OCCURRING

2 )  PROBABILITY OF ZERO EVENTS            RETURN PERIOD, PROJECT LIFE

3 )  RISK OF AN EXACT NUMBER OF            RETURN PERIOD, PROJECT LIFE
     EVENTS OCCURRING                      AND NUMBER OF EVENTS

4 )  DESIGN RETURN PERIOD REQUIRED         RISK LEVEL, PROJECT LIFE
     FOR A SPECIFIED RISK OF EXCEEDENCE
     ASSOCIATED WITH ONE OR MORE EVENTS

5 )  RETURN TO MAIN MENU

                              CHOOSE (1-5) ?
```

Figure 8. Hydrologic risk menu.

Example Problem 1: If the project life of a culvert is intended to be 15 years, and is sized for the 25-year flood, what risk is there of one or more events occurring?

Answer: By choosing option one, and entering the return period (25) and project life (15), the program will use Equation 5 to respond with:

THERE IS A 46 PERCENT RISK OF EXPERIENCING
ONE OR MORE 25-YEAR FLOODS OVER A 15-YEAR PERIOD.

Pushing the return key will return you to the Hydrologic Risk menu where another question may be asked.

Example Problem 2: For the same project as in Problem 1, what is the chance of no events occurring during the life of the project? Enter the same information after selecting Question 2, and the program uses Equation 4 to respond with:

Answer: THERE IS A 54 PERCENT PROBABILITY OF EXPERIENCING
NO 25-YEAR FLOODS OVER A 15-YEAR PERIOD.

Example Problem 3: What is the risk of experiencing only one 50-year flood over a 20-year period?

Answer: Select Question 3 from the menu and enter 50 for the return period, 20 for the project life, and 1 for the number of events. The program uses Equation 3 to respond with:

THERE IS A 27 PERCENT RISK OF EXPERIENCING
EXACTLY 1 50-YEAR FLOOD OVER A 20-YEAR PERIOD.

Example Problem 4: A large culvert is to be installed and the District Engineer has accepted a hydrologic risk of 40 percent. What design return period should be used to size the culvert if the project life is 15 years?

Answer: Choose Question 4 from the menu and enter 40 for the risk level, and 15 for the project life. The program uses Equation 5 to find p, the exceedence probability, and then takes the reciprocal to find the return period, and responds with:

THERE IS A 40 PERCENT RISK OF EXPERIENCING ONE OR MORE
30-YEAR FLOODS OVER A 15-YEAR PERIOD.

Peak Flow Estimation

Choosing the second option from the main menu will show another menu with the geographic regions used by the USGS method (see Figure 9). Select the appropriate geograph region and you will be prompted for the project name. Enter the project name or simply push the return key to proceed. If a project description exceeds 70 characters in length, that portion over 70 characters will be truncated.

```
PEAK FLOW ESTIMATION

USGS METHOD

REGIONS

1 )  COAST REGION
2 )  WILLAMETTE REGION
3 )  ROGUE-UMPQUA REGION
4 )  HIGH CASCADES REGION
5 )  RETURN TO MAIN MENU

CHOOSE REGION (1-5) ?
```

Figure 9. Flood frequency regions menu.

The program will then prompt you for the basin characteristics required for that region. Each prompt will display the range of values used in developing the regression equations. Values outside of the ranges shown may be entered (to a limited extent), but as stated earlier, the results should be qualified accordingly by the user.

After all information is entered, the program produces a table (Figure 10) which shows the estimated peak flows for the 2-, 5-, 10-, 25-, 50-, and 100-year floods. The exceedence probability and peak flow per square mile are also shown. If any of the basin characteristics are outside of the range used in developing the equations, then this will be noted on the output. After prompting for a printout, the program proceeds by displaying the flood estimates in graphical form, which may also be printed out.

You will then be asked if you wish to use the WRRI method to estimate flood peaks. A negative response will return you to the main menu. If the WRRI method is used, the program will prompt for additional basin characteristics if they are needed. Basin characteristics which are outside of the range used in developing the regressions equations are noted on the output of

USGS FLOOD FREQUENCY EQUATIONS: COAST REGION 10-06-1986
PROJECT: McGee Creek Peak Flow Estimates

WATERSHED AREA................. 0.25 SQ. MILES
AREA IN LAKES AND PONDS........ 0.00 %
2-YEAR 24-HOUR RAINFALL........ 3.50 INCHES

AREA OUTSIDE RANGE USED IN REGRESSION .27 TO 667 SQ. MI.
USE ESTIMATED FLOOD FREQUENCIES ACCORDINGLY

FLOOD FREQUENCY ESTIMATES USGS METHOD

RECURRENCE INTERVAL (YEARS)	EXCEEDENCE PROBABILITY (PERCENT)	PEAK FLOW (CFS)	PEAK FLOW (CFS/SQ. MI.)
2	.50	13.3	53.1
5	.20	19.3	77.3
10	.10	23.5	93.9
25	.04	29.0	116.1
50	.02	33.2	133.0
100	.01	37.5	150.2

FLOOD FREQUENCY CURVE
USGS METHOD

RETURN PERIOD (YEARS)	DISCHARGE (CFS)
2	13.3
5	19.3
10	23.5
25	29.0
50	33.2
100	37.5

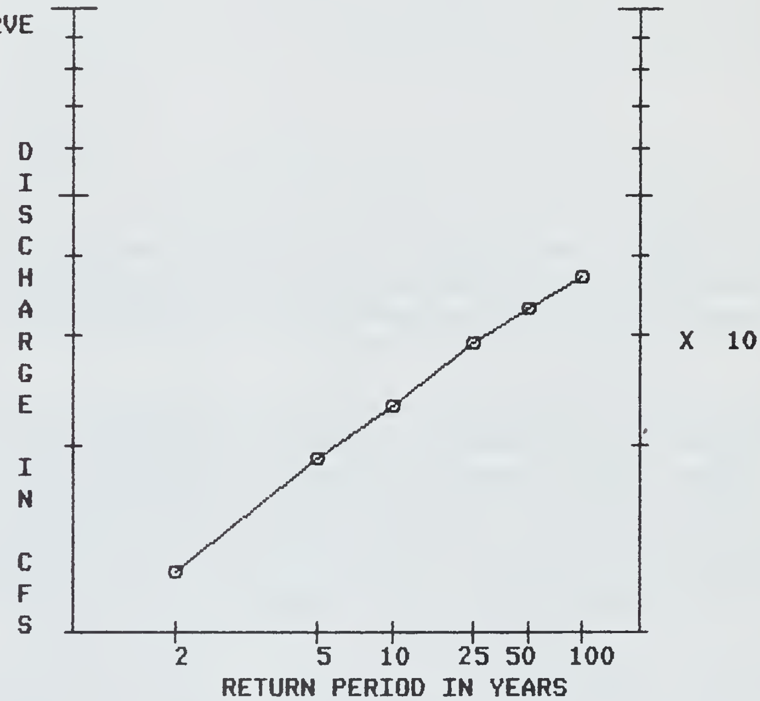

Figure 10. Example output of USGS method.

the WRRI method. The flood frequency table produced (see Figure 11) shows the 10-, 25-, 50-, and 100-year flood estimates in addition to the 95 percent confidence intervals for each estimate. The upper and lower 95 percent confidence values can aid the designer in adjusting the peak flow estimates based upon existing or expected watershed conditions.

WRRI FLOOD FREQUENCY EQUATIONS: COAST REGION 10-06-1986
PROJECT: McGee Creek Peak Flow Estimates

WATERSHED AREA................. 0.25 SQ. MILES
MEAN BASIN ELEVATION........... 500.0 FEET

AREA OUTSIDE RANGE USED IN WRRI REGRESSION .29 TO 2.58 SQ. MI.
USE ESTIMATED FLOOD FREQUENCIES ACCORDINGLY

FLOOD FREQUENCY ESTIMATES WRRI METHOD

RECURRENCE INTERVAL (YEARS)	EXCEEDENCE PROBABILITY (PERCENT)	PEAK FLOW (CFS)	95% CONFIDENCE INTERVAL LOWER (CFS)	UPPER (CFS)
10	.10	29.2	20.0	38.4
25	.04	37.0	24.1	50.0
50	.02	42.8	27.9	57.8
100	.01	47.0	29.9	64.0

FLOOD FREQUENCY CURVE
WRRI METHOD

RETURN PERIOD (YEARS)	DISCHARGE (CFS)
10	29.2
25	37.0
50	42.8
100	47.0
UPPER CONFIDENCE	
10	38.4
25	50.0
50	57.8
100	64.0
LOWER CONFIDENCE	
10	20.0
25	24.1
50	27.9
100	29.9

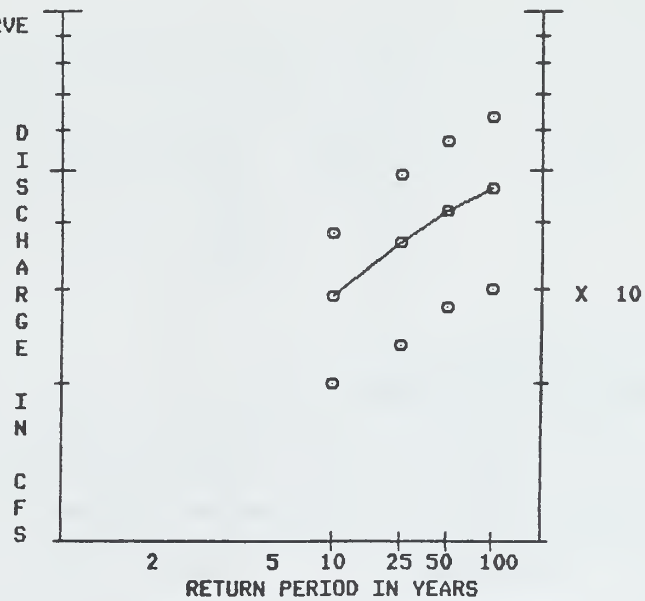

Figure 11. Example output of WRRI method.

The flood frequency table may be printed out before the information is presented in graphical form. As stated earlier, basin characteristics outside of the range used in developing the regression equations may be entered. In some cases, this may produce negative values for the lower 95 percent confidence estimate. If this happens, then the graph will not be produced.

The flood frequency graph and confidence intervals of the WRRI method may be printed out before returning to the main menu. It should be mentioned that while the flood frequency graphs of both the USGS and WRRI method may be used to estimate other recurrence intervals (20-year flood for example), this is not true for the confidence intervals. The confidence intervals of the WRRI method are determined for a single predicted value, such as the 25-year flood. It does not show how the 95 percent confidence intervals vary with the recurrence interval.

Example Problem 1: Flood frequency estimates are needed for a watershed in the coast range. The basin has the following characteristics:

Area	160	acres
Area in lakes and ponds	0	acres
2-year, 24-hour precipitation	3.5	inches
Mean basin elevation	500	feet

What are the USGS and WRRI estimates of the 25-year flood, and what is the WRRI 95 percent confidence interval for the estimate?

Answer: Select Peak Flow Estimation from the main menu, then choose the Coast geographic region. Next, enter .25 for the area, 0 for the percent area in ponds and 3.5 for the 2-year, 24-hour precipitation. The USGS estimated 25-year flood is 29 cfs. After the flood frequency graph is displayed, proceed with the WRRI method and enter 500 for the the mean basin elevation. The WRRI estimated flood is 37 cfs, and the 95 percent confidence interval is 24 cfs to 50 cfs.

Circular Culvert Sizing (Type 1 Flow)

This program option will calculate the diameter of a circular culvert needed to pass a design flow under inlet and headwater conditions specified by the user. The culvert is assumed to be flowing under inlet control (Type 1 flow) as defined previously, and is not applicable to culverts flowing under other hydraulic conditions.

After choosing Option 3 from the main menu, another menu which shows the three entrance types is shown. For a projecting pipe, the program assumes the embankment slope is 1.5H:1V and the invert of the culvert does not project appreciably beyond the toe of the fill. Select an entrance type and then enter the design Headwater/Diameter ratio and the design discharge. The project name is then prompted for. A maximum of 70 characters may be entered.

Once the discharge coefficient Cq has been selected by the program for the proper entrance type and HW/D ratio, Equation 7 is solved for the estimated culvert diameter. Since culverts are manufactured in certain sizes, the estimated diameter is "bracketed" by culvert sizes that come close to the estimated diameter. For instance, if an estimated diameter is 63.4 inches the program will decide whether a 60-inch or 66-inch pipe should be used. If the estimated culvert diameter is within the lower 30 percent of the range between the two bracketing sizes, then the lower diameter is chosen. If not, then the upper size is selected.

The user's design information is then displayed with a table showing the predicted discharges at Headwater/Diameter ratios from .4 to 1.4. Users should compare the design discharge and Headwater/Diameter ratio with the values in the table.

Example Problem 5: A design discharge of 35 cfs has been chosen for a site where peak flows have been previously estimated. Because of potential debris, the engineer has decided the culvert should have a mitered entrance and pass the design discharge with a .7 Headwater/Diameter ratio. What pipe diameter should be used? What flow in cfs may be passed at HW/D = 1.0 for the pipe?

Answer: Select Option 3 from the main menu, and then choose a mitered entrance for the culvert. Next, enter .7 for the HW/D ratio and 35 for the design discharge. The program selects a 48-inch pipe and shows how the pipe performs at other HW/D ratios in table and graphical form (see Figure 12). Notice that approximately 40 cfs may be passed at a HW/D ratio of .7 for this size pipe and approximately 70 cfs at a 1.0 HW/D ratio.

View Culvert Performance

If the performance of a certain size pipe is desired, then the fourth option may be selected from the main menu. After specifying the culvert diameter, the program will produce the tables and graph for that diameter. This feature is useful to evaluate the performance of an existing culvert installation or when a certain size pipe is available for use.

Example Problem 6: If a projecting entrance is used in the above problem, at what HW/D ratio will the design discharge of 35 cfs be passed? How many cfs at HW/D = 1.0?

Answer: Select Option 4 from the main menu and then choose a projecting entrance for the pipe. Enter the diameter of 48. The program shows a 48-inch pipe will pass 36 cfs at a HW/D ratio of approximately .7, and approximately 63 cfs at HW/D = 1.0.

10-06-1986

Flash Creek Crossing

DESIGN DISCHARGE: 35.0 CFS
DESIGN HW/D RATIO: 0.7
ENTRANCE TYPE: MITERED FLUSH WITH EMBANKMENT
TYPE I FLOW, HW/D < 1.5, So > Sc, H4 < Hc

48 INCH CMP

HW/D	CFS	HW/D	CFS
0.4	14.6	1.0	69.5
0.5	22.5	1.1	78.3
0.6	30.6	1.2	90.2
0.7	39.7	1.3	98.0
0.8	49.9	1.4	103.4
0.9	59.3		

CULVERT PERFORMANCE
48 INCH CMP
MITERED ENTRANCE

HW/D RATIO	DISCHARGE (CFS)
0.4	14.6
0.5	22.5
0.6	30.6
0.7	39.7
0.8	49.9
0.9	59.3
1.0	69.5
1.1	78.3
1.2	90.2
1.3	98.0
1.4	103.4

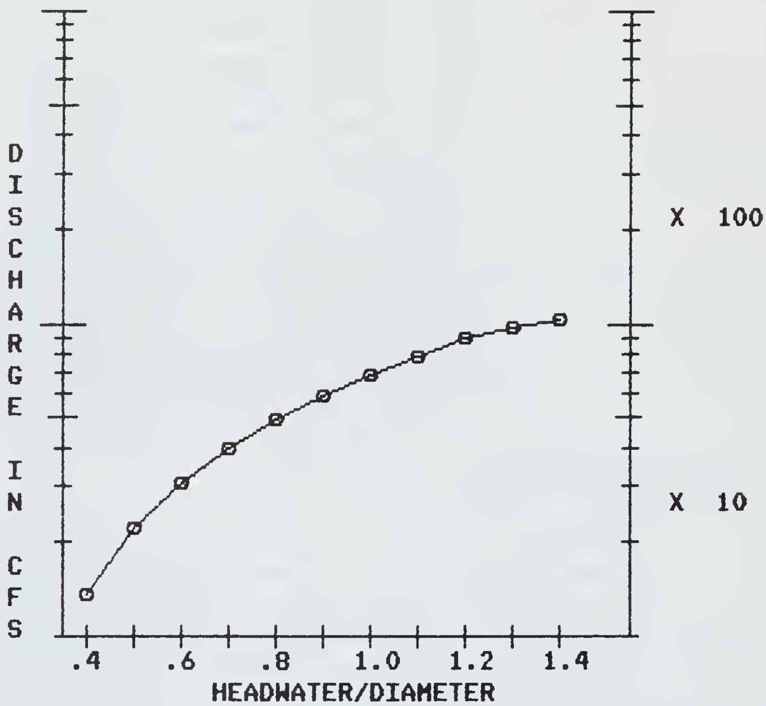

Figure 12. Culvert sizing example output.

Summary Example

Example Problem 7: A stream crossing in the coast region is needed for a timber sale. The estimated life of the project is 15 years and the engineer has accepted a hydrologic risk of 45 percent for the project. The watershed has the following characteristics: Drainage area is 192 acres, percent area in lakes and ponds is 0, the 2-year 24-hour precipitation is 3.5 inches and the mean basin elevation is 500 feet. Find the following:

a) Design recurrence interval.
b) Peak flow estimates for the design flood using both the USGS and WRRI methods.
c) Circular culvert size required to pass the design flow at a HW/D ratio of 1.0.
d) Evaluate the culvert performance for other recurrence intervals.

Answer:

Select Hydrologic Risk Analysis from the main menu. Selecting Option 4 from the Hydrologic Risk menu will determine the design recurrence interval needed for the given project life and risk. Enter 45 for the risk level and 15 for the project life. The design recurrence interval calculated is 26 years, thus using the 25-year flood will be acceptable.

Proceeding to the Peak Flow Estimation option from the main menu, select the coast region from the region menu. Enter .3 for the drainage area, 0 for the percent area in lakes and ponds, and 3.5 for the 2-year 24-hour precipitation. The program will produce the USGS flood frequency estimates (see Figure 13). The 25-year flood is approximately 35 cfs.

USGS FLOOD FREQUENCY EQUATIONS: COAST REGION 10-06-1986
PROJECT: Example Problem 7

WATERSHED AREA................. 0.30 SQ. MILES
AREA IN LAKES AND PONDS........ 0.00 %
2-YEAR 24-HOUR RAINFALL........ 3.50 INCHES

FLOOD FREQUENCY ESTIMATES USGS METHOD

RECURRENCE INTERVAL (YEARS)	EXCEEDENCE PROBABILITY (PERCENT)	PEAK FLOW (CFS)	PEAK FLOW (CFS/SQ. MI.)
2	.50	15.8	52.7
5	.20	23.0	76.6
10	.10	27.8	92.8
25	.04	34.4	114.6
50	.02	39.4	131.3
100	.01	44.4	148.0

FLOOD FREQUENCY CURVE
USGS METHOD

RETURN PERIOD (YEARS)	DISCHARGE (CFS)
2	15.8
5	23.0
10	27.8
25	34.4
50	39.4
100	44.4

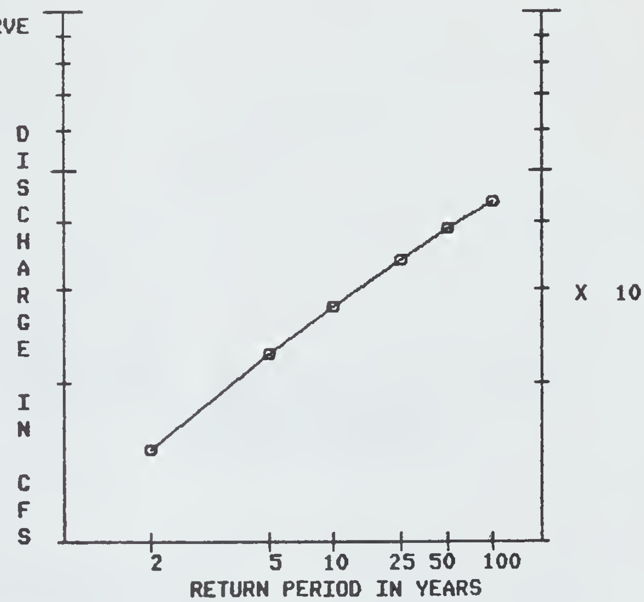

Figure 13. Example Problem 7, USGS method.

If other recurrence intervals are desired, these may be estimated from the flood frequency curves of the USGS or WRRI methods. The calculated values from the program may be plotted on log-probability paper and other recurrence intervals estimated from the flood frequency curve if greater accuracy is needed.

Next, answer yes when prompted for the WRRI method and then enter the mean basin elevation of 500. The 25-year flood estimated by the WRRI method is approximately 45 cfs, with upper and lower 95 percent confidence values of 60 and 29 cfs, respectively (see Figure 14). The peak flow estimates of the USGS

WRRI FLOOD FREQUENCY EQUATIONS: COAST REGION 10-06-1986
PROJECT: Example Problem 7

WATERSHED AREA................. 0.30 SQ. MILES
MEAN BASIN ELEVATION.......... 500.0 FEET

FLOOD FREQUENCY ESTIMATES WRRI METHOD

RECURRENCE INTERVAL (YEARS)	EXCEEDENCE PROBABILITY (PERCENT)	PEAK FLOW (CFS)	95% CONFIDENCE INTERVAL LOWER (CFS)	UPPER (CFS)
10	.10	35.3	24.2	46.3
25	.04	44.5	29.0	60.0
50	.02	51.5	33.6	69.4
100	.01	56.3	36.0	76.7

FLOOD FREQUENCY CURVE
WRRI METHOD

RETURN PERIOD (YEARS)	DISCHARGE (CFS)
10	35.3
25	44.5
50	51.5
100	56.3
UPPER CONFIDENCE	
10	46.3
25	60.0
50	69.4
100	76.7
LOWER CONFIDENCE	
10	24.2
25	29.0
50	33.6
100	36.0

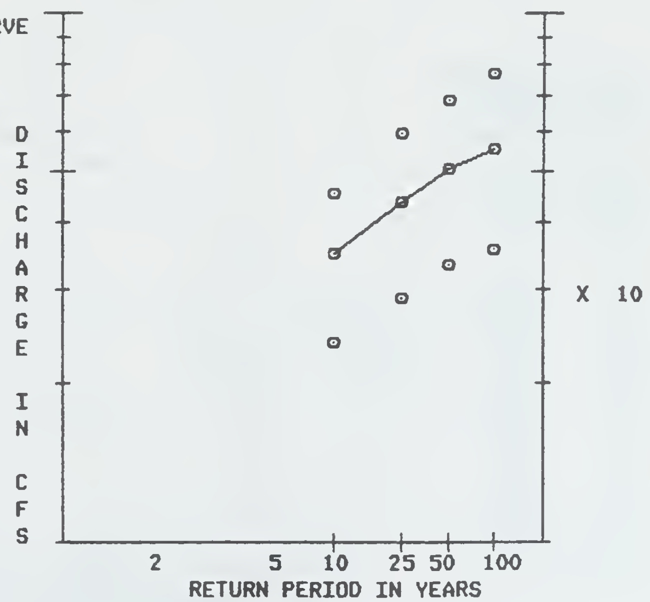

Figure 14. Example Problem 7, WRRI method.

and WRRI methods, as in this case, are frequently not close. By being aware of how the methods were developed and the range of variables used in the regression equations, the user can select an appropriate design discharge. Peak flow estimation is still an art. For this example, a design discharge of 35 cfs is selected.

Returning to the main menu, select Option 3 to determine the culvert size needed to pass 35 cfs. Select the desired entrance type. For the first culvert trial in this example, a mitered entrance was chosen. Then enter 1.0 for the design HW/D ratio, and 35 for the design discharge. Figure 15 shows the program selected a 36-inch culvert. Notice that approximately 34 cfs will be passed at HW/D = 1.0.

10-06-1986

Example Problem 7

DESIGN DISCHARGE: 35.0 CFS
DESIGN HW/D RATIO: 1.0
ENTRANCE TYPE: MITERED FLUSH WITH EMBANKMENT
TYPE I FLOW, HW/D < 1.5, So > Sc, H4 < Hc

36 INCH CMP

HW/D	CFS	HW/D	CFS
0.4	7.1	1.0	33.9
0.5	11.0	1.1	38.1
0.6	14.9	1.2	43.9
0.7	19.3	1.3	47.7
0.8	24.3	1.4	50.4
0.9	28.9		

CULVERT PERFORMANCE
36 INCH CMP
MITERED ENTRANCE

HW/D RATIO	DISCHARGE (CFS)
0.4	7.1
0.5	11.0
0.6	14.9
0.7	19.3
0.8	24.3
0.9	28.9
1.0	33.9
1.1	38.1
1.2	43.9
1.3	47.7
1.4	50.4

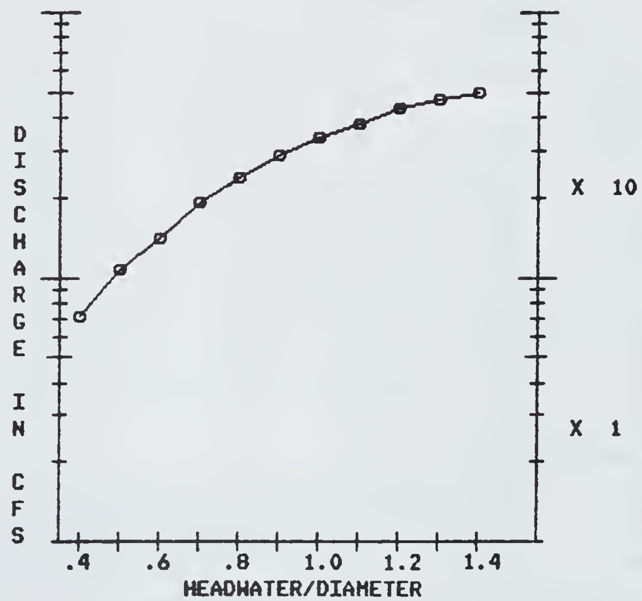

Figure 15. Example Problem 7, culvert sizing.

Looking at the USGS flood frequency estimates (Figure 13), a mitered 36-inch culvert will pass the 10-year flood at a HW/D ratio of approximately .9 (see Figure 15). The 50-year flood will require a HW/D ratio slightly greater than 1.1 and the 100-year flood a HW/D ratio greater than 1.2.

Comparing the WRRI flood frequency estimates (Figure 14) with the 36-inch culvert (Figure 15), the estimated 25-year flood of 45 cfs would require a HW/D ratio between 1.2 and 1.3. The 50-year flood of 52 cfs would probably need a HW/D ratio of 1.5.

A larger size pipe would allow room for debris to be passed during flood events. A smaller design HW/D ratio may be selected and another culvert size determined by repeating the previous steps. Another way is to choose Option 4 from the main menu and select an entrance type and culvert size. Figure 16 shows a projecting entrance was chosen for a 42-inch culvert. Again, the USGS and WRRI peak flow estimates may be compared with the HW/D ratios for this size culvert. The 25-year USGS estimate (35 cfs) would be passed at a HW/D ratio of approximately .8 and the WRRI 25-year flood (45 cfs) would be passed at a HW/D ratio close to 1.0. Thus, if 35 cfs is our design flood, a 42-inch culvert would provide some space for debris during the event. A mitered entrance would provide additional space.

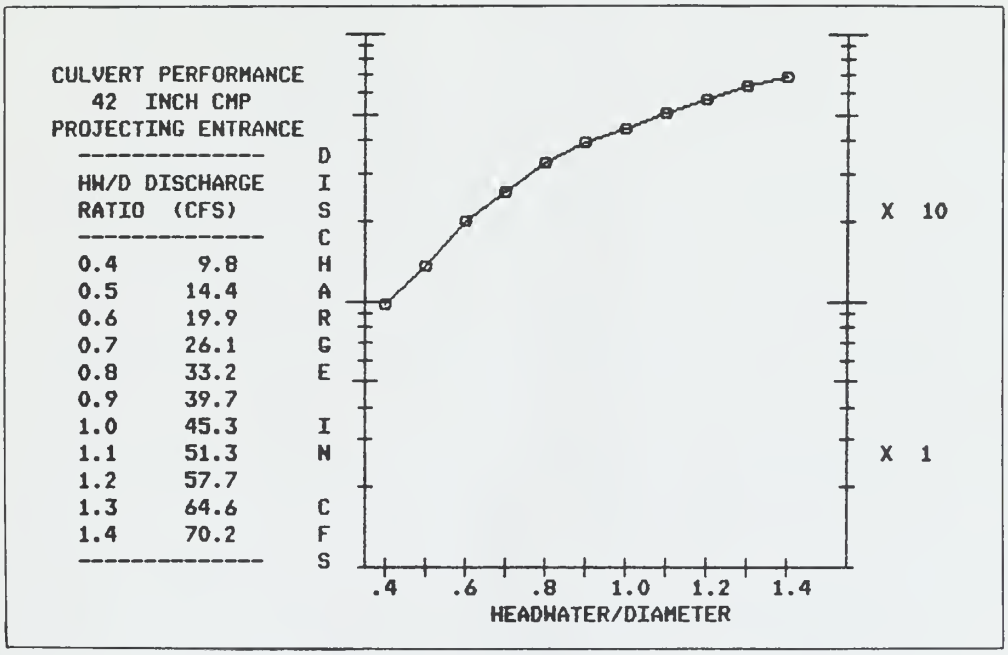

Figure 16. Example Problem 7, culvert performance.

It can be seen from the previous example that culvert selection is more than a cut-and-dry procedure. Hydrologic risk, peak flow estimation, and watershed conditions can be analyzed scientifically, but a fair portion of the design process requires the use of judgment and art. This is where the Peak/Risk/Culvert program can aid the designer. By allowing the estimates and alternatives to be quickly calculated and documented, the designer can focus on using judgment to meet the desired goals.

Bodhaine, G.L. 1968. Measurement of peak discharge at culverts by indirect methods. USGS Techniques of Water-Resource Investigations, Book 3, Chapter A3, Washington, D.C. 60p.

Campbell, A.J., R.C. Sidle, and H.A. Froehlich. 1982. Prediction of peak flows for culvert design on small watersheds in Oregon. WRRI-74, Oregon State University, Corvallis, Oregon. 96p.

Harris, D.D., L.L. Hubbard, and L.E. Hubbard. 1979. Magnitude and frequency of floods in western Oregon. USGS Open-File Report 79-553, Portland, Oregon. 35p.

Herr, L.A. 1965. Hydraulic Charts for the Selection of Highway Culverts. HEC No. 5, Bureau of Public Roads.

Van Haveren, B.P. 1979. Hydrologic risk and return period selection for water related projects. BLM Technical Note 337, Denver, Colorado. 14p.

The diskette available comes with the following files:

BASIC.EXE	WANG BASIC
PRNMODE.COM	Toggles transparent mode on/off
PEAK.BAT	Called from DOS Command Processor. Turns on the transparent mode so codes sent to the printer take effect, loads WANG BASIC and then runs the program called Peakrisk.bas. After exiting the program, transparent mode is turned off, and the user is exited from the DOS Command Processor.
PEAKRISK.BAS	This is the BASIC program Peak/Risk/Culvert.
GP.BIN	Graphics dump routine.

Within the BASIC system, only the files PEAKRISK.BAS and GP.BIN are critical for the program to run. Depending upon how each BLM District has directories and the transparent mode set up on the Wang micro, the other files may not be needed. It was decided to provide all files (including the BASIC system) necessary to run the program from the DOS Command Processor to avoid problems with system configurations. Your ADP coordinator can install the program on the hard disk (Drive C) if desired by establishing a menu choice, probably on the applications menu. The steps to take are:

1) Create a directory on the hard disk named PEAKFLOW.

2) Copy all the files from the floppy diskette to the PEAKFLOW directory.

3) Modify the applications menu to include the program title: Peak/Risk/Culvert. The menu should call the file PEAK.BAT when the program is chosen from the applications menu.

4) Modify program line 1050 to remove the disk-drive designator A:
   Line 1050 is: 1050 OPEN "R",#1,"A:GP.BIN",700
   change it to read: 1050 OPEN "R",#1,"GP.BIN",700

5) Delete the following program lines: 1040, 1090, 1100.

Be sure to save the program so the changes are permanent. Use the name PEAKRISK.BAS when saving the program.

The program expects the transparent mode to be on, if it is not on, then the only effect is that the print size on the printouts will be whatever the current setting is.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BLM/YA/PT-86/010+4341	2.	3. Recipient's Accession No.
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			6.
7. Author(s) Mark Butler			8. Performing Organization Rept. No. TN-374
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15. Supplementary Notes

16. Abstract (Limit: 200 words)

This Technical Note describes the use of a BASIC computer program to aid the hydrologist (and other specialists involved in water projects) in the calculation of design peak flows, evaluation of hydrologic risk, and selection of circular culverts. The program is written for the sizing of circular culverts at forest road crossings, but may be extended to other applications such as bridges, watershed management projects, and other uses where the calculation of design events and hydrologic risk is needed. A discussion of each subject is included in the text, with instructions on how to use the program. Example problems are used to illustrate the program.

The peak flow portion may be adapted to other locations where regional flood frequency equations have been developed. The computational methods are described briefly. For a more detailed discussion, consult the references cited.

17. Document Analysis a. Descriptors

Basic (programming language) 0902
Computer systems programs 0902
Hydrology 0808
Culverts 1313
Computation 1201
Flow Measurement 1402

b. Identifiers/Open-Ended Terms

Peak flows
Circular culverts

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	37
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse

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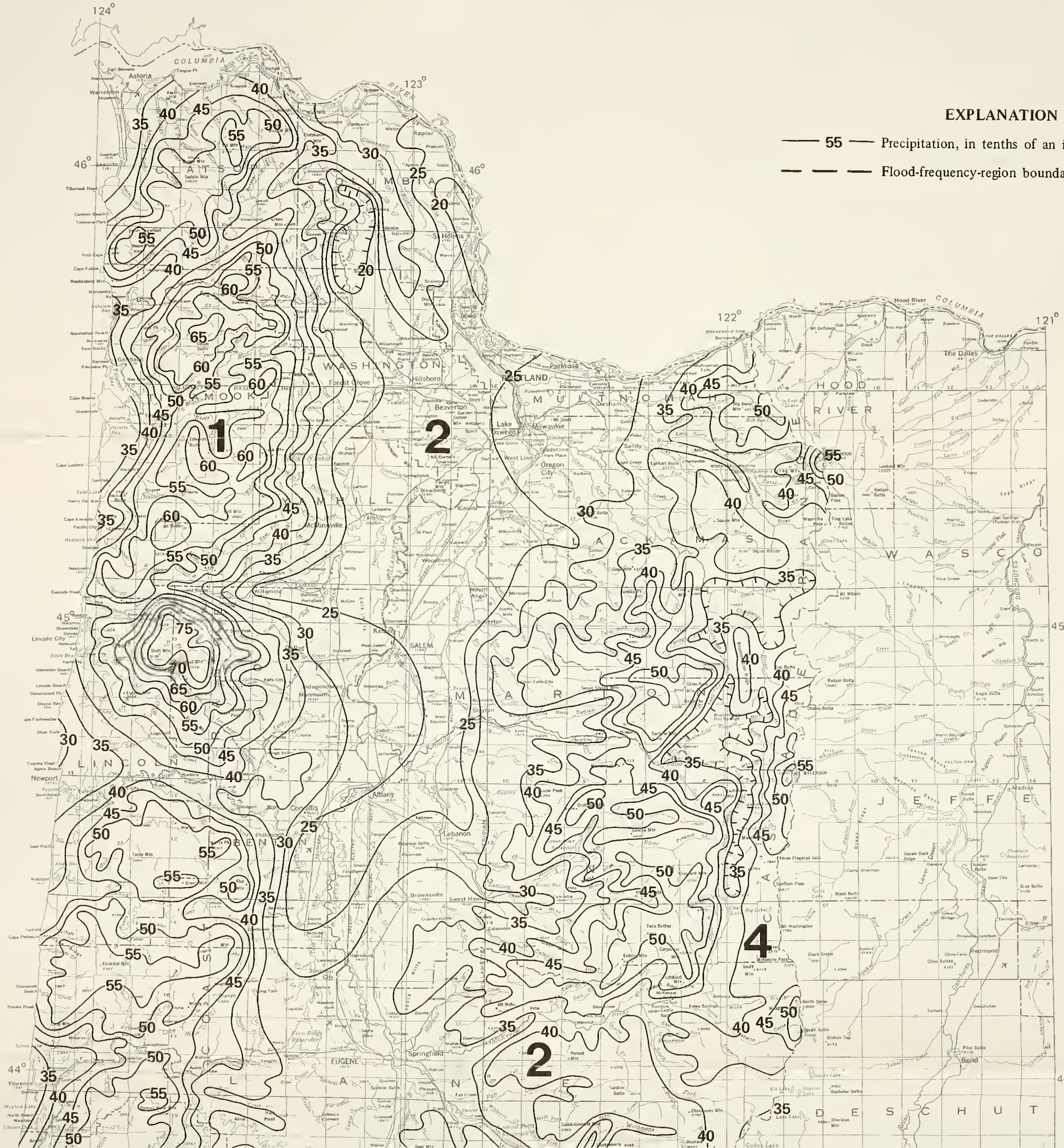

EXPLANATION

—— 55 —— Precipitation, in tenths of an inch

— — — Flood-frequency-region boundary

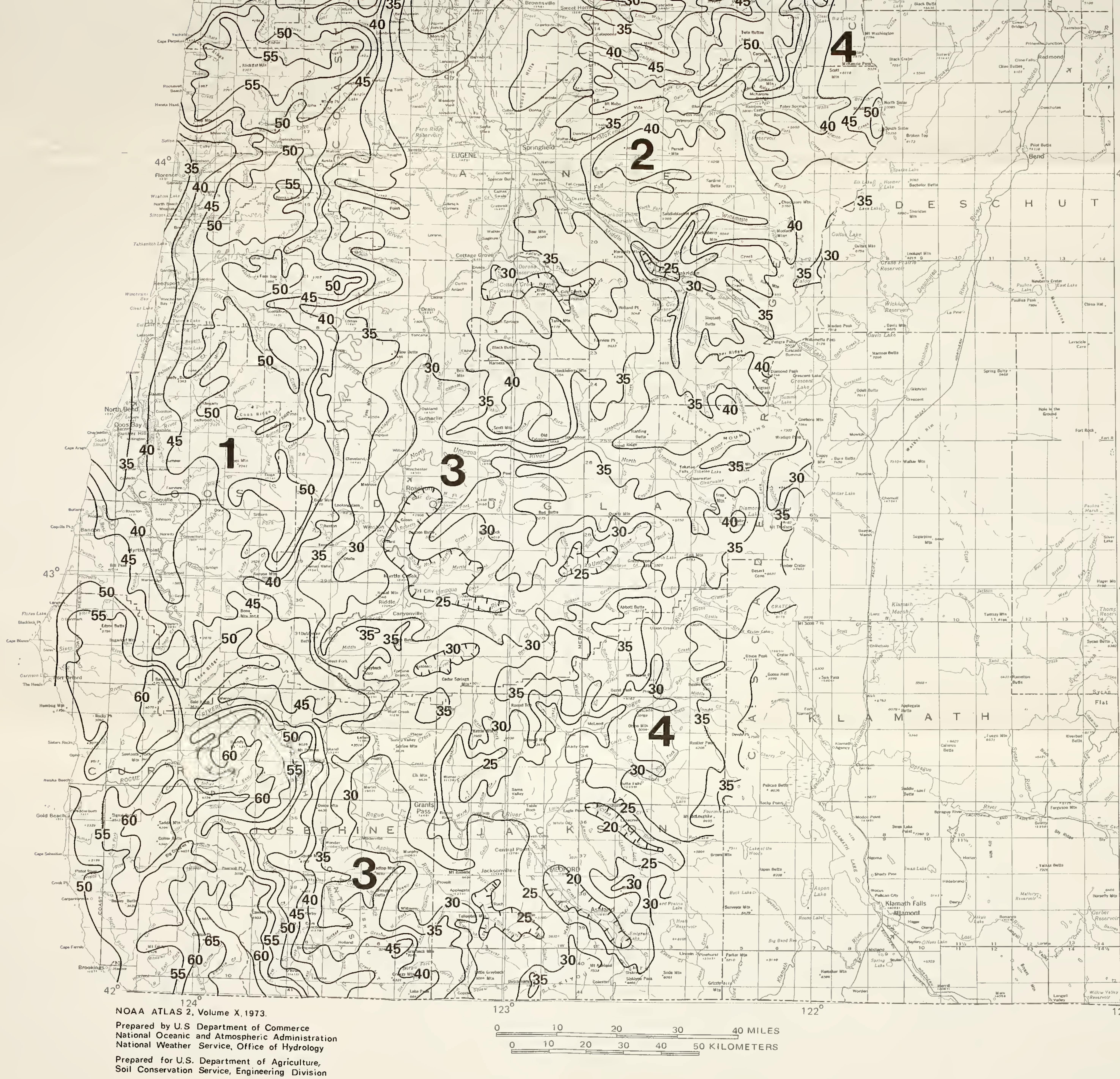

Figure 2. Isopluvials of 2-yr, 24-hour precipitation in tenths of an inch for western Oregon (from Harris et al. 1979).